SAFETY FEATURES OF THE TRANSPORT SYSTEM IN THE TRANSITION TO INDUSTRY 4.0

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Abstract

World trends in the field of intellectualization and digitalization of all activity spheres, caused by the rapid growth of engineering and technology, have caused serious changes in the transport sector. Road transport has a negative impact on the environment, to a large extent this relates to city's air pollution in urbanization conditions and the vehicle fleet accelerated growth. Reducing the negative vehicles impact on the environment is possible only through the development of integrated solutions for managing the transport system. Goal of this article is to study the applicability of decision support systems and simulation models to predict the possibility of reducing the negative vehicles impact on the environment. The developed simulation models for road network problem areas of the Naberezhnye Chelny city allow us to study the influence of traffic parameters on the volume of harmful substances in vehicles exhaust gases, as well as noise pollution. Using the model, it is also possible to assess the possible reduction in the degree of air pollution when converting engines public transport to natural gas fuel. Model experiments showed the adequacy of the proposed approach.

Keywords: traffic flows; simulation model; environmental impact; traffic noise; pollutant emissions

1. Introduction: New Trends in Mobility and Logistics

The global development trends of humanity are associated with growing urbanization. This, in turn, leads to an increase in the need for the movement of goods and population of different countries. According to experts in the mobility field, the main directions in the development of transport and logistics systems are solutions that provide faster, more environmentally friendly and cheaper transportation of people and goods while reducing congestion. This can not only increase public and private well-being, but also contribute to a new wave of economic development.

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For most developed countries, the trends of the new millennium are associated with the rapid development of engineering and technology. Digitalization and intellectualization of processes and systems leads to a change in the economic paradigm, which is expressed in the basic principles of the fourth industrial revolution concept:

- The functional compatibility that the Internet of Things (IoT) implements, which enabling technical systems and people to connect and communicate with each other.
- Information transparency, which is provided by creating a virtual copy of the physical world using data from sensors installed on real-world objects.
- Technical assistance, which providing both through analytical support of the system in decision making and problem solving; and in solving tasks that are too complex or physically dangerous for humans.
- Decentralized decision making, meaning the ability of cyber-physical systems to make simple decisions on their own and become as autonomous as possible.

Industry 4.0 is turning into a real driving force shaping the future of the global supply chain. The technologies association, including advanced robotics and artificial intelligence; sophisticated sensors; Big Data analytics and 3D printing; Cloud based business models powerful mobile devices; and algorithms for driving vehicles (navigation tools, car sharing applications, autonomous vehicles and last mile delivery services) provide interaction between companies, countries, partners and competitors.

These changes will inevitably affect the development of the transport system as a whole. In particular, this is due to the sustainability and safety of urban areas' transport systems. Digitalization and the intelligent industry's formation through innovation will increase the impact on production and logistics processes exponentially. The most significant trends and technologies of the intelligent industry in the coming years will be digital twins, multi-agent systems, cognitive technologies, intelligent things, warehouse robotics, a human-machine interface (HMI), advanced analytics and cybersecurity.

Digital twin (DT) as a virtual representation of a physical object, process, person, data, system or environment is currently used mainly for monitoring machines, modeling production and logistics processes, as well as a tool for analyzing data or predicting possible results. In such cases, the digital twin is used primarily for data analysis and interpretation or prediction of possible results and is extremely passive.

However, in cyber-physical systems (CPS), the digital twins functionality is greatly expanded, allowing the physical object to interact not only in a virtual, but also in a real environment, thereby creating an active digital twin - or, more precisely, an intelligent virtual agent of a physical object. This form of digital twin is widely used in Smart Industry systems for dynamic planning, management and monitoring of production and logistics processes or for supply chain individual segments.

Modern Smart Industry systems use the collective intelligence principles, which based on multi-agent systems in the production and logistics processes and other enterprise's operations. This technology opens up new possibilities for automatic organization (auto-configuration) in an industrial environment, in particular for synchronizing the operations sequence, for example, supplying Just-in-Time material and conveying a semi-finished product. In parallel with the machine independence successful development and them cognitive capabilities expansion, Smart Industry systems will evolve into sophisticated, autonomous industry systems such as Smart Factory.

Cognitive technology is a technology platform that combines hardware and software components, thereby providing cognitive functions that mimic human abilities. They include machine learning (ML), speech recognition, natural language processing (NLP), spatial orientation and computer vision, and will be used for integrated supply chain management as well as for internal logistics (production logistics). The main goals of such projects implementation are, first of all, optimization of the logistics processes efficiency, a significant improvement in the quality of processes.

The digital transformation's next evolutionary stage is the transition between information and communication technologies (ICT), including aspects of artificial intelligence (AI) and operational technologies (OT), which opens up a new phenomenon of intelligent things. Industry will see the machines' dynamic automation, followed by autonomy. Automatically guidance vehicles (AGV) will be transformed into intelligent guidance vehicles (IGV), which will be able to autonomously navigate in space and independently perform all tasks related to the materials supply and products transportation, as well as cooperate with each other as a aggregated object.

Along with new features, new challenges are emerging. So, for management purposes, adequate information is needed, therefore, along with computing power and connectivity, data volumes are growing sharply, which, in turn, requires analytical and business analytical capabilities as key competencies in organizing supply chains.

Artificial intelligence will help sort and process relevant data, metadata, and so-called dark data. Such forms of advanced analytics allow companies to collect data for relevant information, such as behavioral models and correlations, or various predictions, forecasts and recommendations that facilitate the transition from predictive to prescribe analytics. Another part of advanced analytics is the interpretation and visualization of data. The inclusion of natural language processing algorithms (NLP) will further expand the ability to obtain various information, as virtual assistants do today, or in visually understandable formats (as another version of seamless HMI).

The data transmission over the Internet concepts are used in real delivery processes, while intelligent, environmentally friendly and modular containers, ranging from the sea container size to the small box size, become standardized for all companies and countries. These modular containers are constantly monitored and routed, sharing digital communications over the Internet of Things. This requires increased cooperation across the entire logistics sector. The potential is huge - estimates in the EU logistics sector have shown that an increase in efficiency of (10–30)% will lead to savings of (100–300) billion Euros in European industry.

However, the introduction of all these technologies, as well as the exponentially data volumes growing, will require more sophisticated solutions for cybersecurity. Companies should pay more attention to protecting data in databases and data warehouses, as well as preventing data leaks and misuse of confidential information (Data Leakage Prevention – DLP). Enhanced corporate firewalls (next-generation firewalls) become indispensable for companies that need to protect themselves from distributed denial of service (DDoS) attacks or other intrusions and protect the enterprise's production environment from external threats and intentional or accidental employees sabotage.

Goal of this article is to study the applicability of decision support systems (DSS) and simulation models to predict the possibility of reducing the negative vehicles impact on the environment. To increase the process control efficiency in the transport and logistics systems, intelligent solutions are used that allow you to find the best options both at the strategic and tactical management levels. The intelligent heart in decision support systems can be simulation, statistical and dynamic models, as well as Big Data processing algorithms implemented in the form of software modules.

2. State of the Problem: Methods and Models Used to Increase the Sustainability and Safety of Transport Systems

2.1. Factors Affecting Sustainability and Safety of Transport Systems

Considering the issues of stable and safe functioning of transport systems, it is necessary to take into account that only a multilevel approach can provide a holistic vision of processes and possible solutions. So, at a strategic level, a significant role is played by the quality of forecasts, since only in this case it is possible to ensure a balanced development of infrastructure facilities, the level of which will contribute to the safe movement of goods and passengers. If we talk about the operational level of management, it is necessary to take into account the peculiarities of the formation and movement of transport and logistics, passenger and pedestrian flows depending on external factors, such as climatic conditions, time of year, week and day, as well as the psycho-emotional state of various categories of viewers and pedestrians, the technical condition of vehicles and infrastructure, and much more.

Since the functioning of large systems is built in accordance with the system of rules, in recent years, active development has been carried out in the field of intellectualization of large systems, which include transport. The work is aimed at minimizing the role of the "human factor", and, consequently, to improving the security of such systems. Many analysts devote their research to the transition of the transport system to a higher level of intellectualization and analysis of the consequences that this transition will cause. Analyzing possible changes in the transport system during the transition to autonomous cars, analysts evaluate, first of all, the opportunities that the economy and society receive:

- Liberation of a person from the routine task of driving vehicles in routine situations, for example, during prolonged traffic on highways, in traffic jams, in general, in the urban cycle of movement
- Reducing accidents, since it is expected that robomobiles will significantly reduce the number of accidents on the roads. According to forecasts of 2016, the reduction

in accident rate can reach 80-90%. Perhaps this is an overly optimistic forecast, since autopilot robots will make their mistakes typical of robots.

- Improving the economy of vehicle use - due to fuel economy, car sharing, the possibility of round-the-clock use of equipment, etc.
- Savings on the creation of highway infrastructure, since the markup can be virtual - on maps in the autopilot's memory, etc.

However, in most cases, the positive effects have a downside. Thus, the benefit can lead to losses: the most obvious is the fact that removing the "human factor" from the car control system, we create social tension, reducing the number of people involved in the transportation of drivers. In addition, the advantage, designated as "the ability to do some business during the trip", according to doctors, can lead to an increase in ailments due to motion sickness. To avoid this, technical solutions are needed, which can be expensive [20].

Thus, a report by Rand Corporation [4] indicated that in order to maximize the social benefits that this technology will provide, and to minimize its shortcomings, rational political governance will be necessary. However, politicians are just starting to think about the problems and opportunities that this technology creates. The purpose of this report is to help state and federal politicians make wise political decisions in this fast-paced area.

The report [21] discusses the benefits and costs of an autonomous or robotic vehicle, as well as the implications for planning issues. The report provides an analysis of the expansion of the autonomous car market, the benefits and costs and their impact on travel needs and on such planning decisions, including traffic optimization, parking and the development of public transport. According to the authors of the analysis, most of the consequences, including reducing traffic and congestion in the parking lot (and, consequently, saving infrastructure), independent mobility for people with low incomes (and, therefore, reducing the need for public transport), improving security, energy saving and reducing pollution will be significant only when autonomous vehicles become common and affordable, probably in the 2040–2050s, and some benefits may require a ban in some countries the use of human-driven vehicles.

But despite the fact that autonomous cars are still the subject of study and forecasts, safety experts, along with analysts, pay considerable attention to the development of standards and a system of rules in the field of autonomous driving. The US Department of Transportation (USDOT) [27] has released a new Federal Automotive Guide, expanding its commitment to supporting the safe integration of automation into a wide multi-modal ground transportation system. "Preparing for the Future of Transport: Automated Vehicles 3.0" (AV 3.0) is based on, but does not replace, the voluntary guide presented in "Automated Driving Systems 2.0: A Safety Vision". Federal automotive safety standards apply to motor vehicles and automotive equipment; including software for autonomous vehicles. In addition, DOT and NHTSA investigate possible cases of potential defects that adversely affect safety, including using advanced technologies. Any vehicle or vehicle equipment is still subject to recall if there is a safety risk or an unreasonable safety risk.

Cyber security is also of great importance [5, 30], which in the context of road vehicles implies the protection of automotive electronic systems, communication networks, control algorithms, software, users and source data from malicious attacks, damage, unauthorized access or manipulation.

2.2. Ways to Improve the Environmental Safety of Transport Systems: Trends and Solutions

Due to the rapid population growth and the rapid development of the automotive industry, huge problems have arisen in traffic systems, such as traffic jams. In some major cities, traffic jams occur due to several factors, such as roadworks, car accidents, and driver behaviour. Al-Dabbagh et al. [1] identified factors that can increase travel time and listed metrics for measuring traffic jams, and then determined the relationship between the topology of the road network and the level of traffic congestion in relation to travel time and the number of affected vehicles in the event of traffic accidents. The open-source traffic simulator SUMO (Simulation of Urban MObility) was used to simulate the movement of vehicles and create traffic jams on a road map in various scenarios. These scenarios include three road topologies that were: a crossroads in Denver (Colorado, USA), roundabouts in Nantes (France) and a hybrid topology that is a combination of roundabouts and roundabouts in the city of Northampton (UK). The results showed that the delay time is shorter in the topology of the bypass traffic map, and the number of affected vehicles in the event of traffic accidents is less likely to occur in the hybrid topology.

Working areas are widespread in cities of many countries and have a significant negative impact on urban transport. The document [36] focuses on the working area of the circular intersection (islands), and proposes a new model of traffic flow based on the social theory of power. The proposed model can take into account the special characteristics of the traffic flow in the working area of the island, such as heterogeneity, lack of lane separation and an irregular border. Field data collected in Chengdu, China, are used to calibrate and validate the proposed model. The results show that when the island work area is located close to the intersection, this significantly blocks the entry of vehicles. When the working area is more than 1 m from the middle divider, its impact on traffic will become very significant.

Article [15] discusses the problem of reducing fuel consumption and pollutant emissions in heavy vehicles (HDV). The overall goal of improving HDV performance can be achieved through the use of the most advanced technologies in transmission management and intelligent transport systems, taking into account road topography, traffic, weather conditions and driver behavior. The authors believe that it is possible to consider the density of predicted traffic in route planning in order to reduce waiting time and excessive fuel consumption. On motorways and freeways, it is also possible to predict future traffic based on infrastructure databases. Since speed control minimizes fuel consumption, providing an optimal speed profile, and while driving, driver behavior can improve fuel consumption reduction, it is necessary to evaluate the driver's behavior in real time with issuing driving recommendations. The goal of this study is to analyze the impact of driver behavior on reducing emissions in a small, non-congested city. The authors studied parameters such as speed, number of stops, revolutions per minute and maximum acceleration-deceleration in the city of Cáceres (Spain) to collect data on various types of roads in different traffic conditions. This study concludes that environmental driving leads to CO_2 savings of 17% in gasoline engines and 21% in diesel on all routes and types of roads, although travel time is increased by an average of 7.5%. At the same time, the shortest route is the most environmentally friendly, regardless of the volume and characteristics of traffic, i.e. fuel consumption in small cities depends mainly on the distance traveled, and not on traffic patterns in terms of number of stops, speed and acceleration.

Lizbetin et al. [22] are focused on the matter concerning the emissions of the greenhouse gases produced by the road freight transport mode. Article [28] also discusses prospects and problems of using electric vehicles from the point of view of the environmental impact of electric power production. Tsiulin et al. [31] review different barriers, including ecological ones, for development ofurban freight transportation.

One part of the monitoring program at the university campus of RUDN University described in [19] is the control of soil air quality. This is one of the most representative parts of the urban ecosystem, reflecting all the pollution processes in the territory. The results of the measurements were compared: with the maximum permissible concentrations, with background concentrations, with the results of measurements carried out in March 2017. Assessing the state of soils by the absorption coefficient allows us to conclude that a satisfactory state of soils is observed on the campus of the University of PFUR in the forest park zone. In the rest of the territory, the soil is practically incapable of processing or poorly handling pollutants emitted by automobile transport. From this we can conclude that road transport intensively affects the state of the soil.

The aim of [37] is to study the impact of built environment (BE) and emerging transit technologies and cars on greenhouse gas (GHG) emissions associated with home transport in three urban regions. The authors found that BE attributes have a statistically significant effect on GHGs. However, the elasticity is very small. For example, an increase in population density of 10% will lead to a decrease of 3.5%, 1.5% and 1.4% in Montreal, Quebec and Sherbrooke, respectively. There is a significant spread of GHG emissions between houses in the same city, and this spread is much larger than in different cities. In the short term, it is expected that improvements in the private fleet of passenger vehicles will be much more significant than BE and green transit technologies. However, the combined effect of BE strategies and technological improvements in private vehicles will lead to a more significant reduction in GHG emissions in the long term. Other researchers [16, 11] also assess how the infrastructural solutions can influence on negative impacts of vehicles on the environment.

In Poland, as in the rest of Europe, air quality depends primarily on emissions from municipal, domestic and automobile transport sources. Adequate air quality issues are especially important in urban areas, as numerous sources of emissions are concentrated in relatively small spaces both in large cities and in small and medium-sized cities. Due to the steadily increasing share of the urban population in the total population, the problem of providing clean air over the years has become a more important problem for human health and, therefore, is a stronger incentive to intensify research. Eco-driving is a method that helps to reduce fuel consumption, resource requirements and, as a result, reduce atmospheric degradation by reducing carbon dioxide emissions. It also leads to savings in transportation costs (for example, road infrastructure), lower street noise and higher living standards by reducing dust in the air and alleviating the risk of smog. The study [7] shows that gender, age and profession are essential factors in promoting awareness and practice of environmental driving, and, in turn, fuel economy. Models confirm hypotheses and allow an accurate quantitative description of the trends being studied.

Another factor that has a very negative effect on public health is traffic noise. According to studies [26], the total number of vehicles affects the equivalent sound level and emissions at current traffic flow parameters (high traffic intensity with a significant prevalence of cars in its structure), while the influence of their individual groups (trucks, buses and minibuses and other types) slightly.

In this case, the relationship between the noise level and the concentration of pollutants may not be obvious. So, in the studies that we analyzed, based on the obtained correlation coefficients between the noise level and the concentration of pollutants, the authors of the studies characterize this relationship as medium and low. In particular, the study [9] is devoted to the dependence of the number of cardiovascular diseases in the population of Vancouver on the level of noise and air quality. The author carried out a series of measurements, obtained the values of the correlation coefficients and concluded that since the relationship between noise and the concentration of pollutants is not high, the level of cardiovascular disease is primarily affected by noise. Article [8] is devoted to the possibility of using linear regression by monitoring the noise level of determining the quality of atmospheric air without the need to control chemical pollution. However, the obtained correlation coefficient between CO and sound level, equal to 0.68, does not allow, tracking only the noise level, to predict the level of chemical air pollution. In [10], the value of the correlation coefficient is 0.64, and the author of the work concluded that it is necessary to include other factors in his model of step-by-step linear regression for obtaining the values of pollutant concentrations and equivalent sound level.

2.3. Directions of Transport System's Intellectualization: Existing Methods and Models

Reducing the travel time of ambulances is important for saving lives and property. The integration of Intelligent Transport System (ITS) with the EV signal pre-emption, according to [17], is often not applicable due to the operation of EV-signal suppression systems. The authors propose an emergency vehicle signal coordination EVSC approach that will provide a green wave for emergency vehicles (EVs) held along. Numerous traffic measurements are compared between simulations using and without EVSC. The result of AI simulation of movement along an emergency corridor with 8 intersections in Qingdao, China, shows that the proposed approach can reduce the EV travel time by 26.9% with virtually no effect on traffic.

Among the main causes of traffic congestion is a sudden increase in traffic, especially during peak hours. In the event of an unexpected overload, the on-board navigation systems for individual vehicles cannot quickly find the best alternative route. Moreover, using the same alternative routes can lead to new bottlenecks that cannot be avoided. To find a global balance of traffic load, article [35] proposes a multi-agent system (MAS), which can find a compromise between individual and global advantages, offering cars the best options for bypassing a blocked road. The simulation results show that such a strategy can significantly reduce the average trip time in realistic scenarios. In addition, the authors show the importance of altruistic redirection of transport for improving traffic parameters.

Milojevic and Rakocevic [25] propose an algorithm that allows each vehicle in the network to determine the level of traffic congestion in streets spatially separated from the current location. Since the quantification of congestion is based on the data of each vehicle, the algorithm can work even when only 10% of the vehicles on the network support VANET. Data aggregation and adaptive broadcasting are used to manage traffic redundancy information. The simulation is carried out as part of Veins based on the OMNeT ++ network simulator and SUMO mobility simulator.

Article [32] propose an approach based on the Internet of Things to solve some problems arising from traffic jams. This approach contains tools for monitoring a set of environmental parameters, including air quality, as well as for early warning and warning when critical levels are reached, which has a negative impact on the environment and human health, leads to increased economic losses and other problems caused by traffic jams on the roads. To reduce the risk of accidents at the entrance to the road of various vehicles, the authors propose the use of radio frequency identification technology (RFID).

The results of the study [34] emphasize the effectiveness of the motivational context in stimulating the efficiency of eco-driving, which can complicate any information mechanisms, such as, for example, training program drivers. This result departs from previous studies that emphasized environmental incentives and training as a means of reducing emissions and improving fuel efficiency. Article's [38] purpose is to demonstrate the method of mathematical model creation for environmental monitoring at the crossroads. According to Zinko et al., this mathematical model can be used in intelligent transport systems (ITS).

2.4. Decision Support Systems as One of the Effective Methods to Manage the Efficiency and Safety of the Transport System

The decision support system is designed to support multi-criteria decisions in a complex information environment. At the same time, multicriteria refers to the fact that the results of decisions taken are evaluated not by one, but by the totality of many indicators (criteria) considered simultaneously. Information complexity is determined by the need to take into account a large amount of data, the processing of which without the help of modern computer technology is practically impossible. Under these conditions, the number of possible solutions, as a rule, is very large, and choosing the best of them "by eye", without a comprehensive analysis, can lead to gross errors.

DSS decision support system solves two main tasks:

- choosing the best solution from the many possible ones (optimization),
- ordering of possible decisions by preference (ranking).

In both tasks, the first and most fundamental point is the selection of a set of criteria on the basis of which possible solutions will be evaluated and compared in the future (we will also call them alternatives). DSS system helps the user to make such a choice.

Different methods are used for the analysis and development of proposals in DSS. It can be:

- information search,
- data mining,
- search for knowledge in databases,
- case-based reasoning,
- simulation modeling
- evolutionary computing and genetic algorithms,
- neural networks,
- situational analysis,
- cognitive modeling, etc.

Some of these methods have been developed as part of artificial intelligence. If the methods of artificial intelligence are at the heart of DSS, then they talk about Intelligent DSS or IDSS.

Usually in DSS there are four main components:

- information data storages;
- tools and methods for extracting, processing and loading data (ETL);
- multidimensional database and OLAP analysis tools;
- Data mining tools.

The system allows you to solve the problems of operational and strategic management on the basis of credentials about the functioning of the system. Currently, Business Intelligence Systems (BI-systems) are widely used in various industries, the functionality of which includes multivariate data analysis (OLAP), forecasting, a system of key indicators, Data Mining, datamarts, etc.

Direct flight planning, routing and monitoring are currently carried out using geographic information systems, wireless telecommunications RFID, GPS/GSM, WI-FI, which greatly expands the possibilities for optimizing the transportation process. So, the use of GIS, both publicly available, for example, Google.Maps, and commercial, for example, ASRI, allows you to create the shortest routes for vehicles, as well as obtain information about traffic jams, traffic density. Determining the location of the car during the flight, as well as the parameters of its operation (speed, fuel consumption, fueling), taking into account data on the road situation, makes it possible to quickly make a decision on route correction, and also monitor compliance with traffic schedules. In the future, the data obtained from the monitoring system can be used to analyze the performance and profitability of the vehicle. Aggregated information about the traffic flow allows us to calculate its environmental indicators, then, using multivariate analysis, find the best solution for adjusting the functioning of the transport system.

3. Development and Application of DSS for Environmental Management of Transport System: Case Study of Naberezhnye Chelny City

As mentioned above, DSS are one of the most effective means for managing large systems. This is especially true if the system parameters can vary depending on various external factors that are stochastic. In this case, the use of simulation models as an intelligent core allows you to quickly make informed decisions, because that models allow you to take into account many heterogeneous factors of different nature and different change's laws. Therefore, at the first stage, a conceptual framework for DSS was developed, where the following were determined objects: the software modules composition, information sources, modeling tools, the information flows movement. Figure 1 shows the conceptual scheme of DSS, and Figure 2 shows the information flows movement directions.

3.1. Study of Emissions. Proposed Solution

It should be noted that many researchers call the comprehensive study of the existing road network [18, 23] as the basis for improving road traffic. The most effective approach, in their opinion, is precisely the reconstruction of the geometry of the existing network (changing the number of lanes, building fences and road signs) and optimizing the work of traffic lights based on the study of traffic intensity on a specific object [12, 13].

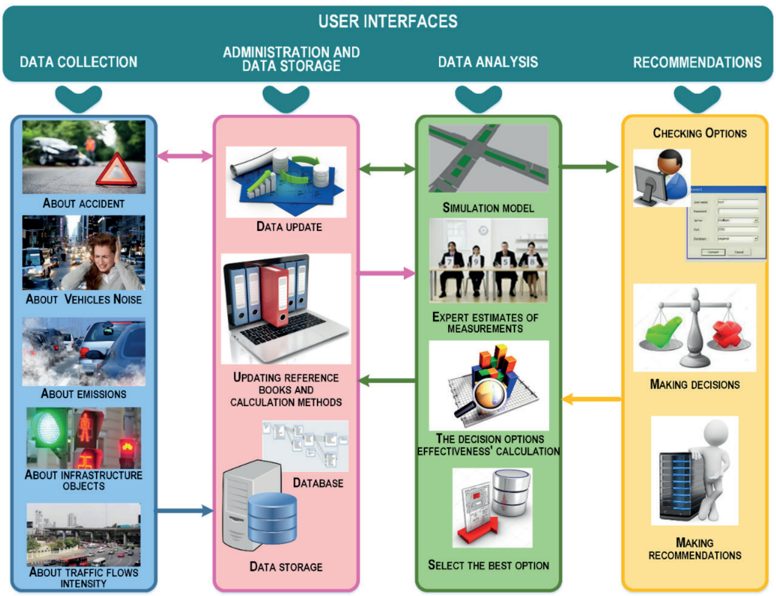

Fig. 1. Conceptual scheme DSS

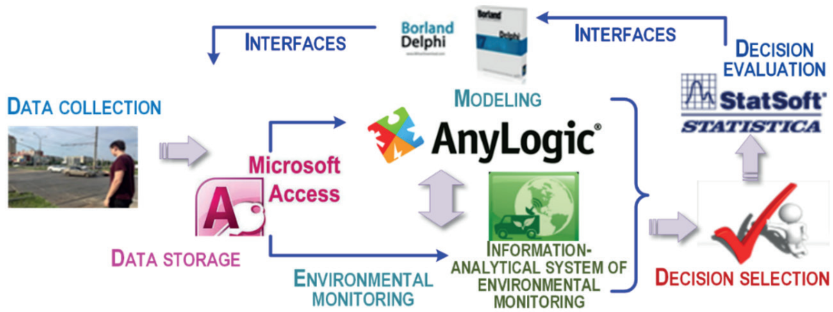

Fig. 2. The information flows' movement directions

Thus, if it is impossible to reduce the intensity of the movement of road transport, it is necessary to adopt such engineering and organizational measures that will help reduce the time of movement of road users. The search for more rational ways to use the existing capacity of the road network implies the creation of ITS [33], which are one of the main tools even if it is impossible to adjust the width of the roadway. In this case, you can improve the transport system by optimizing the operation of traffic lights. With the development of wireless communication between sensors and DSS, it became possible to create intelligent traffic lights, in which operational adjustments of the duration of phases are possible depending on the current traffic intensity. In addition, this event, aimed at reducing the time for a car to travel to a specific section of the road, will contribute to a decrease in the volume of exhaust gases and, as a consequence, the environmental load on this territory.

Among the main causes of traffic congestion, researchers highlight the sudden increase in road load, especially during peak hours. Onboard navigation systems for individual vehicles in the event of an unexpected overload cannot quickly find the best alternative route. Moreover, using the same alternative routes could lead to new bottlenecks that cannot be avoided. To find a global balance of traffic load, Wang et al. [35] offer a multi-agent system that can find a compromise between individual and global advantages, offering cars the best ways to bypass a blocked road. The simulation results show that such a strategy can significantly reduce the average travel time under realistic scenarios. In addition, the authors show the importance of altruistic redirection of transport to improve traffic parameters.

With the rapid development of urban automobilization, road accidents often occur, which negatively affects traffic. To take emergency measures, you need to investigate the time to recover traffic. In article [14], on the basis of the road network and flow characteristics, recovery time and maximum queue length are predicted using the accumulation model of arriving-departing vehicles. To verify the method, the authors used the incident case.

Since the places of concentration of accidents are characterized as problematic from the point of view of the quality of the movement, and with the environmentally friendly one, when choosing a crossroads for modeling, we were guided by an accident map. So for modeling we chose the intersection of Vakhitov prospect – Syuyumbike prospect in Naberezhnye Chelny. The environment for construction a simulation model is the AnyLogic® software package. When developing a model, a traffic library is used. Repeated runs of the model showed that during peak hours on Vakhitov prospect, a serious congestion is created in front of the intersection along Vakhitov Avenue, which increases the amount of harmful substances in this direction. Verification of the model confirmed compliance with the field measurements.

A possible solution to the current problem was to increase the number of lanes from 3 to four on Vakhitov prospect in the problematic direction due to the narrowing of the width of the dividing strip. The histograms of the modified model show that the total number of cars passing increased from 384 units to 446 units in 20 minutes, and the average travel time decreased from 7 minutes to 2 minutes, and the emissions of harmful substances decreased, indicating the efficiency of the proposed option.

One of the problem areas from the emissions point of view is urban areas with fuel filling station located, which create an environmental burden both on their own (evaporation of liquid fuels) and due to the resulting traffic flows at the entrance and exit. We developed a model (Figure 3, Figure 4) of such an area of Naberezhnye Chelny at the intersection of Chulman Avenue and Narimanova Street, taking as a basis an area's satellite image, which shows this areas road network nuances [40]. Both roads are two-way, and have a different number of lanes for traffic in each direction. A feature of this area is the arrival availability to a gas station from Narimanova Street.

The initial data: information on the traffic intensity in each direction, traffic light phases duration, channels number and the average service time at a fuel filling station. Next, the traffic light logic was determined, which will operate in two-phase mode: the first phase will be green for driving along Narimanov Street in the permitted directions, the second phase will be green for entering the intersection from Chulman Avenue and turning right from Narimanov Street. A green light will always be on to leave the gas station, but drivers moving in this direction will have to give way in any case. AnyLogic provides the user with convenient tools for collecting statistics. You can view the statistics of the given road section passage's duration which we are interested in using the chart. It is also useful to turn on the traffic jam display in order to better understand how roads are loaded at a given mode of traffic lights operation (a section of the road is highlighted in green if the vehicle speed is above 60 km/h and red if it is below 10 km/h).

The main goal of building a simulation model is to determine the optimal parameters (the lanes number, the traffic light phases duration, the permissible traffic intensity, the views & age structure of the vehicles fleet, the infrastructure objects parameters) to achieve the minimum or maximum value of a certain functional. Using optimization, in which the selected model parameters are systematically changed, it is possible to achieve a pre-selected target functional.

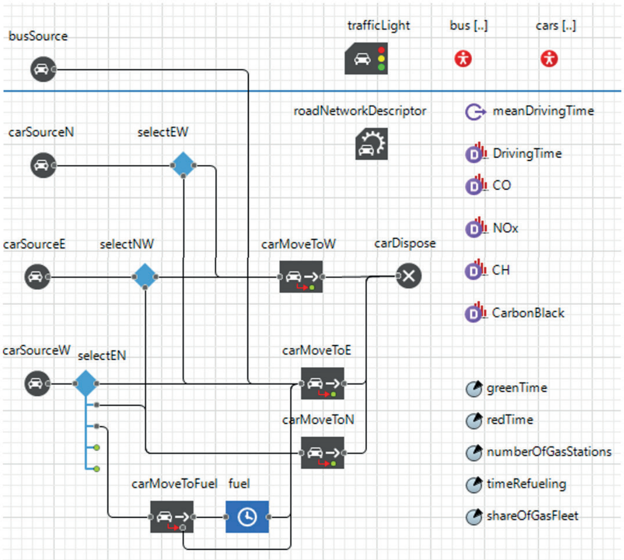

Fig. 3. Structure of intersection simulation model

Fig. 4. Run results of the intersection model for traffic lights current parameters

Through this intersection there passes the city bus route No. 27 (intensity – 5 buses per hour). Since is currently doing transfer public transport to CNG fuel, the model can specify such a parameter as the CNG fuel vehicles' share in the fleet. As the target function, we have chosen the total volumes of harmful substances in the vehicles exhaust emissions, and as the variable parameters, the green or red signal traffic light operating time, as well as the share of the gas-fired vehicles in fleet. The task of finding the target functional extremum in large systems (such as transport systems, logistic systems, etc.) is very difficult and complicated. Different methods can be used to solve it, mainly heuristic methods [2, 29]. We have used the imbuilt into AnyLogic® the OptQuest optimizer (Figure 5), which is a combination of heuristics, neural networks and mathematical optimization. The found parameters values can be used in the model as an optimal strategy that ensures minimal harmful emissions volumes in the vehicles exhaust gases at the intersection.

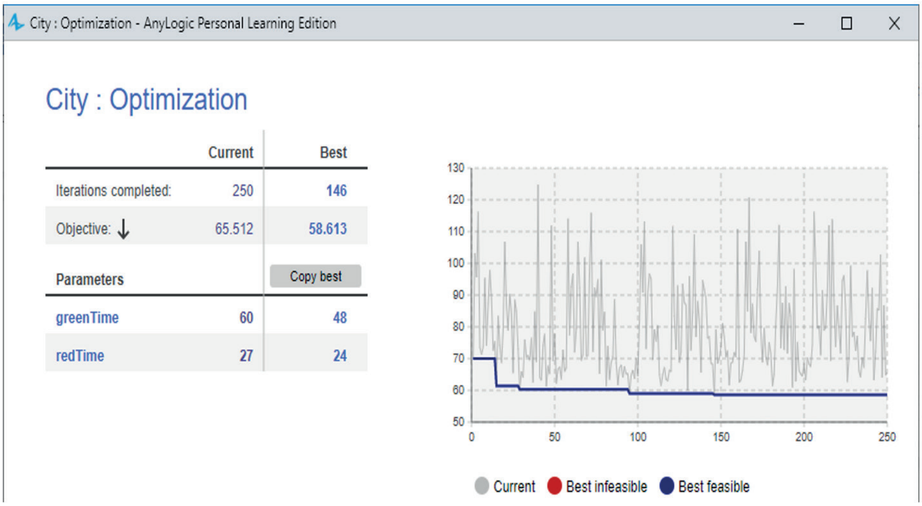

Fig. 5. Results of an optimization experiment

3.2. Traffic Noise. Measures to Reduce the Negative Impact on the Health of City Residents

Noise pollution is another problem that arises when using vehicles. Numerous studies have been devoted to solving this problem [3, 6]. One of the solutions is also to use DSS.

To measure the traffic flow noise characteristics and the pollutants concentration, as well as assess the effect of traffic flow parameters on the noise level and the pollutants concentration, environmental test for surveys of street-road network (SRN) problem areas are necessary, since this is the most effective method for analyzing the situation on the roads. At the same time, specific conditions and traffic indicators are recorded in selected sections of the SRN for a specified period of time. This methods group is currently the most common and is very diverse. Environmental test, being the only way to obtain reliable information about the roads condition, allow us to give accurate characteristics of existing traffic flows. Environmental tests were carried out in the city of Naberezhnye Chelny on Moskovsky Avenue, one of the busiest SRN sections (Figure 6).

To determine the equivalent sound level, we used a 1st class sound meter according to GOST 17187-2010, IEC 60651/60804 and IEC 61672-1-OKTAVA-110A. While measuring the traffic noise characteristics, the microphone was located on the sidewalk or curbstone at a distance of (7.5 ± 0.2) m from axis, the nearest to the point measuring the lane or vehicles path at a height of (1.5 ± 0.1) m from the roadway coverage level.

If the street or road is located in the recess, the measuring microphone is installed on the edge of the recess at a height (1.5 ± 0.1) m from the ground level. It was taken into account that in conditions of buildings compact planning it is allowed to place a measuring microphone at a distance of ‹7.5 m from the axis nearest to the measurement point of the lane or vehicles path, but not closer than 1 m from the buildings walls, solid fences and other structures or relief elements that reflect sound. The mass carbon monoxide concentration in atmospheric air was determined using a gas analyzer using the electrochemical method according to the [39].

According to [24], the equivalent sound level and emissions at current traffic flow parameters (high traffic flow with a significant prevalence of cars in its structure) are affected by the total number of vehicles, while the influence of their individual groups (trucks, buses and minibuses and other types) slightly. The survey results showed that the measured sound level and CO concentration significantly exceeds the maximum permissible (55 dBA and 3 mg/m^3, respectively) at any measured values of the flow intensity (Table 1).

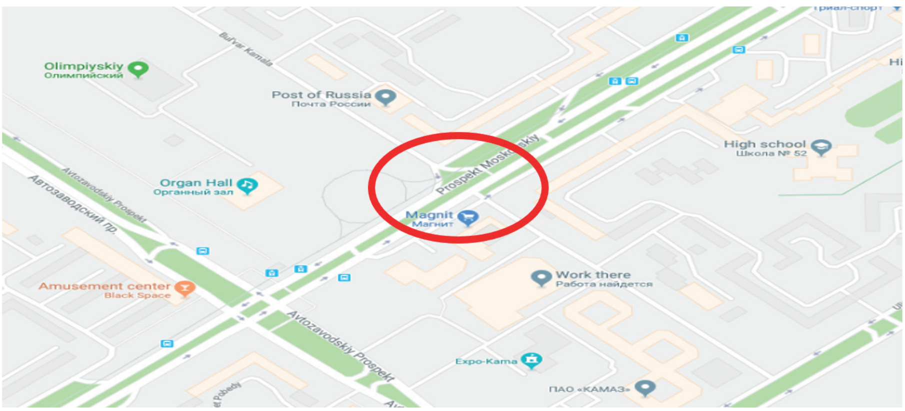

Fig. 6. Results of the field surveys of road network section

The emissions volume was calculated by the formula:

$$G = \frac{m \cdot L \cdot N}{3600} \quad (1)$$

m – is the mileage vehicles emissions,

L – is the length of the section,

N – is the number of passing vehicles per hour.

According to Figure 7, noise pollution and CO emissions monotonously increase with an increase in the number of vehicles passing by, while carbon monoxide concentration is less susceptible to this dependence.

Tab. 1. Measurement results at various traffic flow intensities

Total vehicles number	Equivalent sound level, dBA	CO concentration, mg/m^3	CO emissions, g/s
148	73.5	4.58	4.16
150	73.6	4.60	4.20
148	73.7	4.66	4.20
146	73.5	4.55	4.04
140	73.2	4.61	4.00
135	73.0	4.60	3.92
127	72.9	4.51	3.90
125	72.9	4.57	3.90
124	72.9	4.56	3.90
136	73.0	4.58	3.96
135	73.1	4.53	3.98

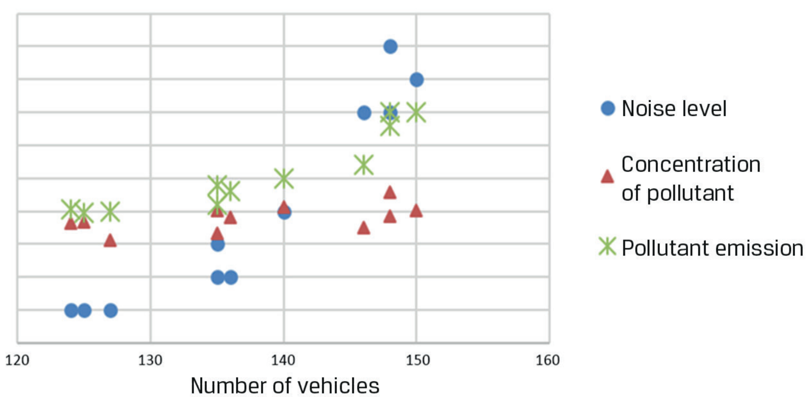

Fig. 7. Sound level, concentration and pollutant emissions by traffic density

Thus, we believe that for urban areas where the main pollution source, both noise and chemical, is road transport, by monitoring the noise level, important data can be obtained regarding the emissions volume, but not the pollutants concentration in the short term in directly investigated area, through the relations obtained using linear regression.

It is worth noting that the mechanisms for generating noise and chemical pollution are somewhat different, as is the way they are distributed. While gaseous pollutants result directly from the internal combustion engine, noise is emitted from the engine and tires and by air displacement.

Engine noise predominates at speeds of 30 km/h and lower for cars (50 km/h for trucks), but at higher speeds "rolling noise" prevails as a result of tire contact with the road. Gaseous air pollutants spread, disperse and have a wider effect, with a greater contribution of background levels to local effects than noise. Noise is transmitted by pressure waves, which can be reflected, refracted, and increased when applied, but otherwise have a short "half-life".

Given the above, it is necessary to continue research to obtain more adequate models by including additional significant parameters in them.

4. Conclusions

The development of engineering and technology opens up new possibilities for the intellectualization of processes and systems. At the same time, the problem of protecting the environment from the negative effects caused by human activities is becoming ever more acute. To a large extent this applies to urban areas, where the level of motorization of the population is growing, as well as the need to move goods and people. The source of noise and air pollution in large cities is mainly road transport. The problem is compounded by the fact that cars, as a source of pollution, are located in close proximity to the human environment. In addition, a direct relationship was found between noise and emissions, which together can cause serious negative consequences, affecting people's health.

At the same time, intelligent technologies make it possible to find solutions in which the negative effects of motor vehicles will be minimized. This includes, but not limited to, management decisions. We provide one of the methods for managing the environmental situation in the city using DSS. Variants of using simulation models as an intelligent core are given.

The experimental results show that using the proposed method it is possible to find optimal solutions from an environmental point of view. The proposed methodology can be used in the other cities with other features of traffic organization. In our future researches we plan to conduct measurements of air and noise pollution in other cities with different sizes and layouts. This will give us the possibility to classify the cities and to make common conclusions in different categories on the basis of results from the city of this category.

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